**Social Networking and Corporate Innovation**[[1]](#footnote-1)\*

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*Abstract*

This paper studies whether board connectedness affects corporate innovation. We find that well-connected boards have a positive impact on innovation activities and quality. The effect of board connectedness is stronger when firms face a greater degree of agency problems or have higher demand for advising. We provide robust evidence that board network facilitates innovation, based on a battery of empirical tests including exogenous variation in board connections resulting from the death and retirement of directors as well as from new exchange listing requirements of the Sarbanes-Oxley Act. We also show that types and relatedness of connections, as well as director characteristics, contribute to cross-sectional heterogeneity of the positive effect.

JEL: G30, G34, L14, O31

Key words: board network, innovation, directors, monitoring, advising

1. **Introduction**

Innovation is critical for economic growth and is vital for firms to gain competitive advantage and long-term success.[[4]](#footnote-4) However, innovation is in general associated with high risk and requires tolerance of early failure, as it is the outcome of a continuous and explorative learning process with potential costly mistakes (Manso (2011)). Risky and lengthy innovative projects may result in information asymmetry, leading to equity undervaluation and takeover attempts (Stein 1988, 1989), and induce managerial myopia.[[5]](#footnote-5) Managers might also prefer a quiet life and pass by value-increasing projects. Boards of directors can play an important role in corporate decision making and innovation particularly. It is well accepted that various factors affect the effectiveness of boards. Social connections among directors can facilitate information distribution and generate superior comparative information advantage. In this paper, we explore the impact of social connections on the value of board’s advisory and monitoring functions in fostering corporate innovation. An effective board provides monitoring over myopic or self-dealing managers and prevents them from passing by valuable innovative projects. This can be carried out in an explicit manner, as a board is the “ultimate legal authority” in a firm and is responsible to review and approve fundamental operating and financial decisions.[[6]](#footnote-6) A board may even initiate transition of a stagnant firm by giving an incoming CEO a clear mandate to engage in entrepreneurial strategies (Grühn, Strese and Brettel, 2016). Implicitly, a board may provide governance through carefully designed and reviewed executive compensation scheme as well as general governance guidelines (Weisbach, 1988).

Directors also serve as advisors that provide valuable strategic counsel. With their related knowledge and experience, they influence corporate decision making, such as CEO appointments (Borokhovich, Parrino, and Trapani (1996)), merger and acquisition (Schmidt (2015)), and in our context, innovation.[[7]](#footnote-7) A director with relevant experience thus becomes critical asset and is often explicitly linked to the future growth of a company. When Starbucks Corporation announced the nominations of Rosalind Brewer, Jørgen Vig Knudstorp, and Satya Nadella to its board of directors in 2017, the company highly values these directors’ knowledge and experience on technological innovation. Starbucks’ CEO and chairman Howard Schultz noted that “Innovation and pushing to alter the status quo are also core to our culture, and by welcoming three world-class, values-based leaders—Roz, Jørgen and Satya—to Starbucks Board of Directors upon their election at the Annual Meeting, we will strengthen our leadership and add unmatched expertise in technology, strategy, and retail to the company at a time of unprecedented change for our industry...”[[8]](#footnote-8)

The recent literature on social network suggests the impact of social interactions on economic activity through different channels. This study investigates whether the social network of directors influences long-term investment, specifically, corporate innovation. On the one hand, it is well accepted that social network serves as an influential channel for information diffusion and resource exchange across individuals and organizations and enhances the overall economic benefits (e.g, Larcker, So, and Wang (2013)).[[9]](#footnote-9) A well-connected board has better access to information about operational environment, industry movements, upstream and downstream firms, as well as overall market and regulatory conditions. This is especially important for decision making over innovative projects as they are irreversible and associated with precarious future payoff. Real options theory suggests that in the presence of uncertainty, firms may induce cautionary behavior by deferring irreversible investments.[[10]](#footnote-10) Greater information flow through networks enables directors to better assist top management in adjusting investment portfolios upon the influx of intervening information accordingly and provide competitive investment strategy that creates first mover advantage in an intense campaign (e.g., Baldwin (1982); Wernerfelt and Karnani (1987)).[[11]](#footnote-11) Mol (2001) shows that boardroom networks enable firms to process information and make strategical decisions accordingly. Burt (1997, 2004) shows that social connections provide individuals with alternative valuable viewpoints when there is a lack of guiding reference or the situation is uncertain. The enhanced information flow from networks also helps board of directors assess managerial performance and provide quality governance. For example, Coles, Wang, and Zhu (2015) find that firms with more connected boards make better decisions in CEO replacement and appointment. Social networks also provide reputational incentives that increase directors’ commitment to effectively advise and supervise management actions (Fama and Jensen (1983); Mace (1971); Weisbach (1988); and Masulis and Mobbs (2014)). Taken together, a well-connected board may assist and motivate top management to identify quality innovative ventures with better information and incentive, resulting in better corporate innovation outcomes.

On the other hand, board connectedness may hinder corporate innovation. To the extent that a well-connected board might also be a busy board, as directors may serve on multiple boards and engage in many social activities, such directorship may induce less attention on monitoring and advising top management (Fich and Shivdasani (2006)). A better connected director may also provide less effective service at a lower cost compared to other directors. Prior studies find that board connections are associated with shorter unemployment duration after a director is displaced and greater likelihood of additional directorships afterward (e.g., Cingano and Rosolia (2012); Granovetter (1995); Mazerolle and Singh (2004); Munshi (2003)). If the penalty of being ineffective adviser or monitor is lower for well-connected directors, we may observe a negative relation between network and innovation.

We begin our analysis by gathering network information among board members with other top executives and directors from BoardEx. A connection between two individuals is identified if their social networks overlap, including overlapping current or past professional employment, educational background, and social activities. We then aggregate these individual connections to construct the measure of overall board connectedness and examine its impact on corporate innovation. Our main finding is that corporate innovation increases with board connectedness after controlling for common drivers of innovative activities. Specifically, we use National Bureau of Economic research (NBER) patent database to obtain firm patenting activities as a proxy for innovation output.[[12]](#footnote-12) Consistent with the hypothesis that board network facilitates information exchange, the results suggest that well-connected boards are associated with both larger patent counts and larger subsequent citation counts. The relation is both statistically and economically significant. For example, firms with well-connected boards on average have 55 patents filed each year and 852 subsequent citations adjusted by weighting-index, compared with only 2 patents filed by firms with poorly-connected boards and 63 weighting-index adjusted citations. Multivariate analysis shows similar results.

We perform a battery of robustness check to mitigate potential endogeneity issue that may alter our inference. We control for other potential explanations of cross-sectional variation of innovation output, such as CEO external ties, CEO-director ties, co-opted board, director ages, other governance mechanisms, etc. We also employ alternative specifications including using 3-year lead innovation output measures and R&D as a proxy for innovation input as dependent variables, employing originality and generality of patents to capture the underlying value of patents, considering directors’ connections in their previous positions and residual connections from a de-trend approach, including firm fixed effects, and applying Poisson and Negative Binomial regression model specifications. Our results are robust to these alternative specifications.

To further explore the causal link between board connectedness and innovation, we examine whether changes in board connections resulting from death or retirement of board members affect patenting activities. We find strong evidence that a loss of connected director due to death or retirement causes a significant decrease in innovation outcomes, compared to that from a loss of an unconnected director. We obtain similar results when only including the death events with causes that are sudden. Further, we use Sarbanes-Oxley Act (SOX) enacted in 2002 (and contemporaneously followed by the NYSE and NASDAQ) that imposes changes in the exchange listing rule as our second identification strategy. The Act mandates that listed firms have a majority of independent directors on the board. Such requirement generates an exogenous change in the composition of board for non-compliant firms, which allows us to isolate the effect of board connectedness on corporation innovation (Linck, Netter, and Yang (2009)). We find consistent and supporting evidence in this setting. Together, these quasi-natural experiments further suggest causal effect of board network on corporate innovation. Lastly, we utilize an instrumental variable approach with the number of industries that a director has worked in and the number of death and retirement events as instruments. The results remain robust to this model specification.

We further examine how the cross-sectional variation in demand for advising and agency problems alters our results, so as to identify potential underlying channels through which board connections nurture innovation. We find that the positive effect of board network is stronger if the firm has higher advising need or if agency conflicts between managers and shareholders are more severe. This evidence implies that board network improves innovation through both the advising and monitoring channels, the two functions of boards. Additionally, we explore whether the effect of board connectedness is heterogeneous by sorting connections based on types and centrality of connections, whether the connections are with firms in the same industry, whether the connections are with innovative firms, and the connected director’s type and relative importance of her directorship. We find that all three types of connections are correlated with higher numbers of patents and citations, but the network stemming from overlapping employment has a stronger impact than the network stemming from education and social activities. In addition, we find the positive effect is stronger if the connections are with individuals at firms in the same or innovative industry, with well-connected individuals, stemming from independent directors, or stemming from independent directors who rank the firm higher among their multiple directorships. This evidence further helps us to substantiate the positive effect of board connectedness on firm patenting activities.

Our findings add to the growing literature on the influence of social network among board of directors. Studies show that board connections enhance information dissemination, thus facilitate the spread of corporate practice such as acquisition activity (Haunschild (1993)), the adoption of poison pills and golden parachutes (Davis (1991); Davis and Greve (1997)), and going private in change-in-control transactions (Stuart and Yim (2010)) . There is also empirical evidence that firms with more connected boards make better decisions in acquisition (Schonlau and Singh (2009)), CEO replacement and appointment (Coles, Wang, and Zhu (2015)). Our results show that board connections have a positive effect on corporate innovation which leads to value creation in the long-term.[[13]](#footnote-13)

Our findings also contribute to the burgeoning literature on the determinants of corporate innovation. Many of these studies draw tension onmanagerial incentives from various firm and institutional perspectives. For example, Brav, Jiang, Ma and Tian (2014) find that hedge fund activism improves target firms’ innovation efficiency. Chang, Fu, Low, and Zhang (2015) show that non-executive employee stock options have positive effect on corporate innovation.[[14]](#footnote-14) Custódio, Ferreira, and Matos (2015) and Hirshleifer, Low, and Teoh (2012) show that managerial characteristics such as general managerial skills and overconfidence affect innovation. Several other papers emphasize the market condition and developments such as financial market development (Hsu, Tian, and Xu (2014)) and financial sector deregulation (Chava, Oettl, Subramanian, and Subramanian (2013)). Our paper extends this line of research by providing evidence on the causal effect of board network in promoting firm innovative activities.

Our paper is most related to the limited research investigating the impact of directors’ connections and experience on a firm’s innovative activity. Kang, Liu, Low, and Zhang (2014) study how non-professional connections between the CEO and directors in a firm affect corporate innovation and find positive relation between the two. Dasgupta, Zhang, and Zhu (2015) show that social connections between suppliers and customers enhance suppliers’ innovation. Faleye, Hoitash, and Hoitash (2014) find industry expertise enhances board effectiveness in advising on corporate innovation. Our paper differs from these studies in three ways. First, we investigate how board members’ external network affects corporate patenting activities. Second, we propose and show that the dissemination of information and knowledge around the boardroom through social network enhances both advising and disciplining of the board in terms of firm innovative ventures. This finding therefore adds to the empirical literature of the less explored advisory role of boards and supports the argument of Dass, Kini, Nanda, Onal and Wang (2014) that advising and monitoring roles can be simultaneous and complementary if a director has certain characteristics or information, such as high connectedness, that makes her a better advisor and able to provide more effective monitoring to the management. Third, we provide an extensive set of evidence on how the types and relatedness of connections, as well as director characteristics, contribute to the cross-sectional heterogeneity of the positive effect on corporate innovation.

The remainder of this paper is structured as follows. Section 2 describes the data and variable measurements, and summarizes key firm and board characteristics. Section 3 discusses our empirical results and robustness tests. Section 4 explores potential channels through which board network affects innovation while Section 5 presents further analyses based on various network types and board characteristics. Section 6 concludes the paper.

1. **Data and sample**

 In this paper we use BoardEx as the source of individual information of directors and executives in U.S. publicly listed firms. The BoardEx database provides social network data on directors and executives of over 14,000 public and private companies in the United States and Europe. Firms are matched with a list of directors with complete biographic information including the director’s name, date of birth, job title, role description, and the beginning and ending dates for each past and current position. Educational background, such as years attending an institution and the degree obtained, and social activities are also available. Following prior research (e.g., Cohen, Frazzini, and Malloy (2008)), we reconstruct the time series of board structure using directors’ historical biographical and directorship files. The reconstruction of director information allows us to extend the sample period to as early as 1990.[[15]](#footnote-15)

For each firm in our sample, we first match firms in BoardEx with Compustat based on CUSIP and CIK and apply a string matching approach based on firm name when these two identifiers are not available (e.g., Engelberg, Gao, and Parsons (2013)). This allows us to obtain all necessary accounting information for publicly listed firms in our sample. We then identify social ties between each director and a pool consisting of directors and executives in our sample firms. We do not restrict the network to that among directors because we believe a connection between a director and a top non-director executive in another firm is as important to corporate innovation. Our results are however robust if director-executive ties are excluded from the analysis.

Finally, we match our data with the NBER patent database to obtain information on companies’ patenting activities. We exclude financial firms and utilities from our sample. Our final sample consists of 54,398 firm-year observations from 1990 to 2008.

**A. Measure of board network**

We construct social connections between two individuals using information about their current and past employment, educational background and other social (nonprofessional) activities, respectively. Two individuals share an employment connection if they are currently or were previously employed by the same firm, other than the firm of interest, at the same time. They share an education connection if they attended the same educational institution and overlap in time. They share an activity connection if they both have or had memberships in a non-business organization, such as golf clubs or charities. Following Fracassi and Tate (2012) and Engelberg, Gao, Parsons (2013), we require a director and her linked individual to hold active roles in all organizations except clubs by excluding the connections where either or both individuals are only “members”.

Two individuals are defined as sharing a social connection if there is one or more connections of these three types between the two. We then count how many corporate directors and executives a firm’s board of directors are connected to, and use the aggregate number of connections (*Board network*) for our main analysis. In extended analysis, we provide results of tests on each specific type of connections.

**B. Measure of corporate innovation**

 We use patent-based metrics to proxy for firms’ innovative activity as they measure the innovation output that also incorporates the effectiveness of firms’ use of innovation inputs as in Chemmanur, Loutskina, and Tian (2014). We obtain information on patenting activities from the NBER patent database which covers detailed information for patents granted by the United States Patent and Trademark Office (USPTO) from 1976 to 2006. We also make use of Harvard Business School patent database to update patenting information up to 2008.[[16]](#footnote-16) Our first measure of firms’ patenting activity is the number of patents applied and finally granted by USPTO in a given year. We use the application year rather than the grant year to measure a firm’s innovation in a given year as studies such as Griliches, Pakes, and Hall (1988) suggest that the application year is closer to the actual time of innovation activities. We do not include the last two years available (2009 and 2010) in our sample due to a well-known truncation issue on the lag between patent application and grant date (Hall, Jaffe, and Trajtenberg (2001, 2005)).[[17]](#footnote-17) Our second measure includes two variables of the number of subsequent citations received by all patents of a firm filed in a given year. We correct for the truncation bias in patent citations using the weighting index (Qcitation) and technology class-year fixed effect (TTcitation) approaches by Hall, Jaffe, and Trajtenberg (2001, 2005). We use the natural logarithm form of each of these measures to mitigate bias introduced by outliers.

**C. Control variables**

 Following previous studies, we control for various firm and industry characteristics that affect corporate innovation. In our baseline regressions, our control variables include R&D intensity (*R&D*) defined as R&D over total assets, leverage ratio (*Leverage*), the ratio of cash to total assets (*CHE*), the ratio of capital expenditure to total assets (*CAPX*), asset tangibility (*PP&E*) defined as property, plant, and equipment over total assets, firm size (*Size*) defined as natural logarithm of the book value of total assets, growth opportunities (*Tobin’s Q*), profitability (*ROA*), industry concentration (*Herfindahl index*), and the number of board members (*Board size*). All variables are winsorized at the 1st and 99th percentiles to minimize the effect of outliers that might bias our estimations. Detailed information about variable construction is provided in Appendix.

**D. Summary statistics and univariate comparison**

 Table 1 presents summary statistics for our main variables. On average, a sample firm has approximately 14 patents granted each year, about 126 weighting-index adjusted citations (*Qcitations*), and 9 fixed effect adjusted citations (*TTcitations*), respectively. An average (median) firm has a board of 6 (6) directors and a total of 655 (408) connections. With regard to other control variables, an average firm has total assets of $2.2 billion, 6% of assets in R&D, leverage of 21.3%, and Tobin’s Q of 2.14.

 In Table 2, we segregate firms into two subgroups based on the sample median of board connections and compare the patenting activities and other firm characteristics between these two groups. We find that firms in the well-connected group on average have 54 patents, compared with only 2 patents for poorly-connected firms. An average firm in the well-connected group also has 852 (54) *Qcitations* (*TTcitations*) while an average firm in poorly-connected group has 63 (3) *Qcitations* (*TTcitations*). The differences between these two groups on all three measures are both statistically and economically significant, indicating that board connectedness is correlated with patenting activities and outcome. In addition, an average well-connected firm is larger, invests more in R&D, and has higher leverage ratio and greater growth opportunities. However, when compared with poorly-connected firms, well-connected firms have lower capital expenditure and are in less competitive environments.[[18]](#footnote-18)

1. **Empirical analysis and findings**

In this section, we first provide our baseline analysis on the effect of board connectedness on innovation outputs, proxied by the numbers of patents and subsequent citations in Section 3.A. In Section 3.B, we provide robustness checks based on alternative explanations, additional variables, and other model specifications that might alter our inferences. To further mitigate the endogeneity concern, we rely on deaths and retirements of board members that create an exogenous shock on board connections and report the results in Section 3.C. In addition, we utilize SOX as a quasi-natural experiment that results in the change of board connections to isolate the direct impact of board connectedness on innovation and present the results in Section 3.D. Finally, Section 3.E reports the results using two-stage least square approach as supplementary evidence.

**A. Baseline analysis**

 As a first step to explore the relation between board connectedness and innovation outcomes, we estimate the following baseline regression model:

 (1)

where denotes one of our innovation measures for firm i in year t+1 (*Patents*, *Qcitations*, and *TTcitations*). The key variable is which measures the overall connections of board members in year t. is a vector of firm- and industry-level control variables in year t. We also include industry fixed effects based on two-digit SIC codes and year fixed effects in the model.

 Table 3 reports the results of the baseline regression on how board connections affect a firm’s patenting activities. The regression estimates reflect the elasticity of corporate innovation outcomes to board connectedness, given that innovation outcomes and board connectedness are both in logarithm format. Model 1 of Table 3 shows that board connections is positively and significantly associated with patent counts. Economically, a firm at the 75th percentile in terms of board connections receives 33% more patents than a firm at 25th percentile.[[19]](#footnote-19) Models 2 and 3 report the regression estimates based on adjusted citation counts. The estimated elasticities of *Qcitations* and *TTcitations* to board connections suggest that a change of board connections from 25th percentile to 75th percentile leads to a 65% (33%) in *Qcitations* (*TTcitations*), holding everything else constant.

 In Models 4 to 6, we replace the number of board connections with a dummy variable equal to one if a firm’s board connectedness is above the sample median (*Network dummy*). The regression estimates provide us with similar results. For example, a well-connected firm (with board connections greater than the sample median) has 4.12% more patents compared to a poorly-connected firm.

 Overall, the results show that well-connected boards are associated with higher level of corporate innovation. Such evidence is consistent with the hypothesis that board connectedness facilitates information exchange and improves the advising and monitoring functions of directors.

**B. Robustness checks and endogeneity issues**

**B.1 Alternative measures of board connections, innovation, and model specifications**

We perform a series of robustness tests to ensure our results are not spurious due to different model specifications or endogenous concerns such as omitted variables or reverse causality. First of all, as the construction of our network measures reflects accumulation from past establishments of connections, we employ directors’ residual connections using a de-trend approach to mitigate concerns that a latent time trend possibly drives our results. Specifically, we first regress the raw value of connections with a constant and a time dummy, then take the residual from the regression as our new measure of connections.[[20]](#footnote-20) Panel A1 of Table 4 shows that our results are robust when using this alternative measure of board connectedness. Panel A2 presents the regression estimates using the ratio of board connections over board size as another measure of network. The significant results suggest that the correlation between board connections and innovation found earlier is not driven by a correlation between board size and innovation. Panel A3 reports the results based on Negative binomial method to address the discrete nature of patent counts.[[21]](#footnote-21) Also, in untabulated results, we apply a Poisson regression model and find our results are robust to these alternative model specifications. In Panel A4, we exclude firm-year observations with no patent information and find our results remain robust.

Fracassi and Tate (2012) show that CEO-director external connections undermine the monitoring role of boards, which in turn lead to more value-destroying acquisitions. Coles, Daniel, and Naveen (2014) note that directors appointed by current CEO may exert less effort in monitoring. Yet, Adams and Ferreira (2007) show that a management-friendly board can be optimal in that it provides value-enhancing advice due to better information sharing between the CEO and the board. Boards that emphasize advising relative to monitoring may benefit from CEO-appointed directors and CEO-director connections, improve collaboration between these two parties, and result in greater innovation. To make sure our results are robust to these factors, we include the fraction of directors appointed by CEO (*Co-opted board*) and the number of external connections between the CEO and directors (*CEO-director connections*) as additional controls.[[22]](#footnote-22) Panels A5 and A6 reveal that our findings are not affected by these additional considerations. Further, literature generally agree that independent directors play an effective monitoring role in the boardroom (e.g., Weisbach (1988); Yermack (2004)). In Panel A7, we include the fraction of independent directors (*Independent board*) as an additional control. Our results remain unaffected.

A CEO’s network not only offers the CEO better access to relevant information that potentially reduces the riskiness of innovative projects but also provides a safe harbor to insure the re-employment opportunity (Faleye, Kovacs, and Venkateswaran (2014)). We add *CEO connections* to our baseline model to test if our findings are affected by the relation between CEO network and corporate investment. Panel A8 shows that our results remain robust. Finally, other governance mechanisms may affect corporate innovation. Aghion, Van Reenen, Zingales (2013) provide evidence that institutional investors can incentivize managers to engage in innovative projects through moderating agency problem from the aspect of managerial career concerns. In a similar vein, Atanassov (2013) shows that a weak governance induced by the passage of antitakeover laws lowers corporate patenting activities. These governance mechanisms could also alter the practice of board monitoring. In Panels A9 and A10, we add the percentage of institutional holdings and G-index in the regression, respectively. The results are robust after we consider these alternative governance mechanisms.

In untabulated results, we conduct additional tests by adding annual stock return or stock volatility to proxy for CEO ability, using raw value of board connections, different constructions of historical network, etc., our results remain unaffected.

**B.2 Reverse causality**

 There might be a concern that an innovative firm may attract well-connected directors. For example, having a directorship in innovative firms might help directors to build up her reputational capital and experience (e.g., Fama and Jensen (1983); Mace (1971)). To mitigate this concern, we first employ 3-year lead innovation measures as our dependent variable that creates a sufficient lag between the dependent and independent variables; such historical values on independent variables are more likely to be pre-determined hence less affected by firm innovation performance (Faleye (2007)). Panel B1 of Table 4 shows that our results still hold.

Second, we include a 1-year lag term of the innovation measures as an additional control to reflect possible observed and unobserved heterogeneities on future innovation (Harford, Mansi, and Maxwell (2008)). The results are reported in Panel B2. We continue to find our results remain robust under this model specification.

Finally, we replace the current director’s connections with the first-year connections from directors’ last positions since the connections in the first year from their previous job is less likely to be correlated with a firm’s current innovation performance. This approach helps us to partially mitigate the possibility that a contemporaneous endogenous effect might drive our results. Panel B3 reports the results and shows that our findings are not prone to a fiction of a reverse causality story.

**B.3 Potential omitted variables**

A director’s connections may link to the experience and knowledge that she accumulates over her careers; hence, connections may simply be a proxy for the director’s ability. On the other hand, directors with greater ability may also help to enhance innovation outcome. To mitigate the concern that director ability might contribute to the positive relation between board connectedness and innovation, in Panels C1 to C3, we add the average age of board members, the number of directors with a graduate degree, and the average director tenure in the regression, respectively, and find similar robust results.[[23]](#footnote-23)

Further, in Panel C4, we conduct a firm fixed effects regression model to control for unobservable time-invariant firm characteristics that might create this spurious relation between board network and innovation. We find our results are robust under this alternative model specification.

**B.4 Identification**

 Based on the findings from above sections, we find suggestive evidence that board connectedness affects corporate patenting activities. To further mitigate the endogeneity concerns, in this section we conduct a set of identification strategies to substantiate the causal effect of board connections.

1. *Retirement and death of directors*

Our first identification strategy is to utilize a difference-in-difference (DID) approach by identifying events of director deaths or retirements that result in a decrease in connectedness. Firms are not able to immediately find a new replacement with equal connections for a departed director (Fracassi and Tate (2012)). Falato, Kadyrzhanova, and Lel (2014) show that firms are unlikely to replace a deceased director within two years of the event. Such events thus generate plausibly exogenous variations in board connections that are less likely to be correlated with firm decision makings. Following Fracassi and Tate (2012), we first identify 388 deaths and 2,582 retirements in our sample.[[24]](#footnote-24) A director’s retirement is identified if the director leaves the firm at or above the age of 65.[[25]](#footnote-25) Of the deceased (retired) directors in the sample, 296 (2,086) directors had at least one connection. Thus, events of deceased and retired directors with loss of connections are considered as treated events while those directors without connections are regarded as control events.

We conduct a difference-in-difference analysis where we include a 5-year window centered on the event year and require that there is at least one observation both before and after the event year. We include a dummy variable *After* that equals 1 for years after the year of death or retirement. The coefficient on variable *After* helps us to capture the average within-firm effect of departures of unconnected directors on innovation. We also interact *After* with a treatment dummy *Connected* that equals 1 if the director deceased or retired had at least one connection. This interaction term between *After* and *Connected* is included to isolate the incremental effect of board connectedness on corporate innovation in a difference-in-difference setting.[[26]](#footnote-26) We include firm fixed effects in all regressions and cluster standard errors at the firm level to moderate concerns that an individual firm can experience multiple departure events.[[27]](#footnote-27)

 Table 5 reports the regression results from the DID specification. In Panel A, The coefficient on *After* is negative and significant suggesting that innovation activities decrease after the exit of unconnected directors. The coefficient on the interaction term between *After* and *Connected* is also negative and significant at 1% level. In terms of economic magnitude, this departure effect of connected directors represents an additional 14% drop in innovation in terms of patent counts, relative to the departure of unconnected directors. This finding suggests that director deaths or retirements associated with loss of connections have a more substantial impact on innovative activities compared with the departures without loss of connections. Panel B restricts our sample to firm/years around deaths of directors only. We continue to find that the interaction coefficient between *After* and *Connected* is negative and significant, although with much fewer observations.

 To further substantiate our results, we conduct extensive news search to identify cases of sudden death among these deceased directors. Given there is no universally accepted definition of sudden death, we classify a death event as sudden if the cause of death is linked to stroke, accidents, murder, or heart attack or if the cause is not specified but described as sudden.[[28]](#footnote-28) Thus, the cases where deceased directors suffered from prolonged illness or complications from diseases or surgery are excluded from our sample of sudden director death.[[29]](#footnote-29) For the sample of 388 deceased directors, we are able to identify 65 sudden death events including 54 connected directors and 10 unconnected directors. Panel C presents the results of DID analysis for this subsample of sudden deaths. A major drawback of this rather strict screening is that a relatively small sample could undermine the power of the test, yet the coefficient on the interaction term between *After* and *Connected* is significantly negative at the conventional level. In untabulated results, we classify death as sudden only if it is explicitly stated to be unexpected regardless of the cause of death. The results are robust to this more restricted definition of sudden death. In general, our findings suggest a causal impact of the change in board connectedness due to director death or retirement on corporate patenting activities.

We perform a set of robustness check on this DID test by replacing firm fixed effects with industry fixed effects, creating a restricted sample with firms having only connected or unconnected director departures in a given year, requiring each event firm to have two years both before and after the event, expanding our event window to 7 years, constructing a randomized balanced sample between our treated and control events, including director or firm-director fixed effect, and limiting our sample to firms with departures of connected director only. Our results still hold with all of these alternative specifications.

 To address the concern that our DID results might reflect an unobservable time trend, we conduct a placebo test by creating a “*pseudo-event*” year that is three years before the actual event year. We then perform the DID estimations as above. Panels D, E, and F report the regression estimates based on our “*pseudo-event*” sample. The interaction coefficient between *After* and *Connected* is statistically insignificant and smaller in magnitude. We also shift our event year 4 years and 5 years before the event year and find similar results. This robustness test based on the “*pseudo-event*” year lends us further confidence that our departures are unlikely to capture other unobservable shocks or trends.

1. *Sarbanes–Oxley Act (SOX)*

To further address endogeneity issues, we exploit the new listing rules enacted by Sarbanes–Oxley Act (SOX) in 2002 and contemporaneously adopted by NYSE and NASDAQ. We collectively refer to post-SOX period for the period starting from year 2002 (Linck, Netter, and Yang (2009)). The new listing requirements mandated firms to have a board with majority of independent directors, thus imposed an exogenous variation in board structure. Non-compliant firms were obligated to increase the board independence, which generates an exogenous change in board composition and allows us to identify the clean effect of board connectedness on innovation.[[30]](#footnote-30)

 Following Coles, Daniel, and Naveen (2014), we apply a modified difference-in-differences specification to isolate the “clean” effect of board connectedness as follows:

 (2)

where is an indicator variable equal to 1 if the year is 2002 and afterwards while is also an indicator variable equal to 1 if a firm is not compliant in year 2001. All other dependent and independent variables are defined as above. We use a 4-year event window around year 2002 for a balanced panel.[[31]](#footnote-31) Based on this specification, captures the effect of board connectedness on innovation for compliant firms while captures the effect for non-compliant firms. Further, represents the effect of connectedness for complaint firms in the post-SOX period where captures the direct effects from SOX. All of these three elements (, , contain the bias from endogeneity. Finally, as SOX imposes an exogenous shock on board composition of noncompliant firms, captures both the clean effect of connectedness on innovation and the direct effects from SOX. Hence, one can obtain the clean effect of connectedness () by subtracting the direct effects of SOX () from the combined effect (). Specifically, given that non-compliant firms are required to increase board independence, provides us with the clean estimate of connectedness on corporate innovation from the resulted exogenous variation in board network (see Coles, Daniel, and Naveen (2014) for a thorough elaboration).

 Table 6 reports the regression results with the clean estimates at the bottom of the table. From Models 1 to 3, we observe the clean estimates of the effect of board network, derived from the exogenous variation in board connections through SOX, on patenting activities are positive and significant. This evidence helps us to mitigate concerns that endogeneity might drive our results.

1. *Instrumental variable approach*

We apply the instrumental variable method as an alternative attempt to mitigate potential endogeneity issue. Our first instrument is the median number of industries that directors have worked in based on two-digit SIC codes. To the extent that the more industries that a director has worked in, the greater likelihood that she can interact with more people, this instrument is correlated with the overall board connectedness. And, there is no a priori reason that this instrument should be directly related to innovation. Our second instrument is the number of director departures due to death or retirement.

Model 1 of Table 7 reports the regression estimates from the first stage. The dependent variable is the number of board connections. The instruments *(No. of industries* and *No. of departures*) have the expected effects on board connections and are statistically significant. For example, the number of industries that directors have served has a positive effect on board connectedness, indicating that diversified industries experience increases a director’s opportunities to be bounded with other directors and executives. The number of director deaths and retirements has a negative impact on board connections, suggesting that firms are not able to find an immediate replacement after the departure of connected directors. The Kleibergen-Paap Wald rank F-statistics that largely exceeds the critical value for 10% maximal size suggests that the instruments are jointly strong (Stock and Yogo (2002)). The p-value of Hansen J statistic at the end of the table also indicates that we cannot reject the null of overidentifying restrictions. Models 2 to 4 report the estimates from the second-stage regression. The results show that the predicted board network is positive and statistically significant at the 1% level. Collectively, our results above lend us further evidence on the effect of board connectedness on corporate patenting activities.

1. **Potential mechanisms**

Our findings so far reveal that well-connected boards foster corporate patenting activities. In this section, we lean on prior literature and examine two possible and non-mutually exclusive underlying channels, boards’ monitoring and advising functions, through which board connectedness nurtures corporate innovation (e.g., Adams and Ferreira (2007); Fama and Jensen (1983)).

**A. Advising**

The first channel through which board connectedness nurtures firm innovation is through the advising capacity of directors that enhances information flow for business decision makings, strategical development, opportunity identifications, and deployment of corporate resources (e.g., Adams (2009); Adams and Ferreria (2007); Demb and Neubauer (1992); Monks and Minnow (1996); Song and Thakor (2006)). Following previous studies, we consider firm size, degree of diversification, and R&D intensity to verify the degree of complexity of a firm. To the extent that complex firms have greater need for board advising, we expect the influence of board connectedness to be stronger for firms that are larger, more diversified, and R&D intensive.[[32]](#footnote-32)

We first segregate our sample into two subgroups based on the median firm size (sales). Table 8 Panel A1 reports the regression estimates. In each pair of columns, we first report the results for low advising need group and then for high advising need group. Further, in Table 8, Models 1 and 2 of each panel provide results using the number of patents as the dependent variable while Models 3-6 use the adjusted number of citations based on weighting index and fixed effects as the dependent variables. As predicted, we find that board connections have a greater impact on firm innovation in terms of patent counts and adjusted citation counts. The test of difference between the coefficients on board network of two subgroups rejects the null hypothesis at the 1% significance level. We then split firms into two subgroups by defining firms with more than (less than or equal to) two segments as high (low) advising group. The regression estimates in Panel A2 indicate that board connections have greater impact on diversified firms’ patenting activities. Lastly, we partition firms into two subsamples based on the median R&D. The results, reported in Panel A3, show that the effect of board connections is stronger for R&D intensive firms. In untabulated results, we also perform subsample analysis based on total assets and foreign sales and obtain similar conclusions. Overall, the above results provide us with assurance that board disciplining and advising mechanisms constitute as plausible mechanisms through which board connectedness affects firm patenting activities.

**B. Monitoring**

A large stream of literature has demonstrated the importance of directors as effective monitors by examining their diligent disciplining influence on CEO turnover (Guo and Masulis (2015); Weisbach (1988)), executive consumption of perquisites (Brickley and James (1987)), adoption of internal governance practices such as poison pills (Brickley, Coles, and Terry (1994)), corporate information environment (Armstrong, Core, and Guay (2014)), evaluation of acquisition activities (Byrd and Hickman (1992)). Board connections may improve governance and reduce potential agency conflicts, as social network offers directors with greater access to information needed to assess managerial performance (Coles, Wang and Zhu (2015)) as well as higher incentive to exert effort in monitoring due to a reputation effect. Thus, we expect that board connectedness is more influential on innovation outcomes when high agency conflicts and weak governance are present.

To test this hypothesis, we split our sample into two subgroups based on the sample median of proxies of corporate governance, estimate the baseline models in each subgroup separately, then compare the impact of board network in the two subgroups. We first consider the entrenchment index (E-index) from Bebchuk, Cohen, and Ferrell (2009) where they note that an increase in E-index is associated with a reduction in firm valuation and that such negative association is consistent with the presence of poor governance in the first place. Again, in each pair of columns in Panel B, we first present the estimates for the low agency conflict group and then for the high agency conflict group. Based on the regression estimates in Panel B1 of Table 8, we find that board connectedness has a greater impact on innovation for firms with higher level of E-index. The test of the equality of coefficients rejects the null that the difference of the coefficients between these two subsamples is zero at the 1% significance level.

We test the hypothesis using two alternative proxies for governance. Prior literature suggests that CEO duality may impede corporate governance (e.g., Fama and Jensen (1983); Jensen (1993)). Thus, we divide firms into two subsamples based on whether a CEO is also the chairman of the board. Panel B2 of Table 8 reports the coefficient estimates and the statistics of tests comparing between firms with dual leadership structure and firms without such structure. The coefficient estimates from Models 2, 4, and 6 suggest that board connectedness has a greater impact on innovation outcome for firms with dual leadership structure as these firms may suffer from ineffective monitoring. Manso (2011) notes that standard pay-performance incentive schemes may result in managerial myopia that hinders optimal corporate innovation. To test our conjecture that board connectedness enhances effective monitoring, we estimate the sensitivity of the dollar value in CEO equity portfolio to a dollar change in stock price (*Delta*) following Core and Guay (2002) and partition the sample into two subgroups based on the sample median of *Delta*. Given the monitoring effect of board, we expect the influence of board connections on firm innovation to be stronger in the high *Delta* group. Panel B3 reports the regression estimates. The estimation results are consistent with our expectation. The test for the difference between the coefficients of these two subgroups also reject the null hypothesis with a p-value of at least 5% significance level. In untabulated results, we also use institutional block holdings, analyst coverage, CEO age, and scaled wealth-performance sensitivity (Edmans, Gabaix, and Landier (2009)) to proxy for potential agency conflicts and find similar results.

1. **Further empirical analysis**

In this section, we further investigate the heterogeneity in the effect of network due to types and relatedness of connections as well as some board characteristics. We then look at the effect of network on the input and fundamental nature of innovation.

**A. Heterogeneity in network and board characteristics**

Our measure of total board connections is the sum of three types of connections: employment, education, and other social connections. We include the number of all three types in the regression and report the results in Panel A, Table 9. The regression estimates suggest that all types of network contribute to the positive effect on firm patenting activities. However, network stemming from overlapping employment has relatively stronger effect than education networks and social activity network. This is consistent with our expectation, as individuals with whom a director shares an employer, previously or currently, are more likely to share useful information with the director and improve the director’s effectiveness on the board.

Second, we break down our network measure by separating connections with individuals from the same industry as the focal firm (*Same ind. network*) from those connections with individuals from all other industries (*Other ind. network*) based on two-digit SIC codes.[[33]](#footnote-33) To the extent these same-industry connections can provide valuable industry-specific information related to industry opportunities, operational environment, and regulatory changes, we expect that same-industry connections will have stronger effect on innovation. Panel B presents the regression results. As our analytical prediction, the coefficient on *Same ind. network* has a relatively greater magnitude. This finding is consistent with the notion that industry-specific knowledge and network of directors can further benefit firms that are more complex or innovative in production (e.g., Coles, Daniel, and Naveen (2008); Dass, Kini, Nanda, Onal, and Wang (2014)). In a similar vein, we also reclassify our network measure into connections with individuals from innovative industries and from non-innovative industries. We define an industry as innovative if the average weighting-index adjusted citations per patent is above the sample median across all industries based on two-digit SIC codes. Panel C reports the results and shows that both types of connections have positive effect on innovation. A test of equality of coefficients between these two measures rejects the null at the 5% significance level. This suggests that connections stemming from innovative industries are more likely to provide valuable information related to innovation activities.

To better understand the relative importance of a director in the network, we borrow the concept of centrality from the network theory. The intuition is that a better connected director has greater opportunities of information exchange, thus a firm’s connections with her are more influential than connections with a less connected director. An individual is defined as better connected (central) if the total number of her connections is above the sample median. Similar to the way that we separate connections with same industry firms from connections with firms in other industries, we create two measures of network by calculating the total number of connections with better connected individuals (*Central network*) and the total number of connections with less connected individuals (*Non-central network*) for each firm. Panel D shows that the coefficient on *Central network* is positive and significant at the 1% level while the coefficient on *Non-central network* is statistically insignificant. This result supports our conjecture that a more influential person has advantage in accessing quality information.

Next, we explore whether independent directors have a stronger impact on innovation. Prior literature finds that because of reputational concerns, independent directors are effective in their roles of monitoring and advising (e.g., Fama and Jensen (1983); Weisbach (1988)). We thus classify our measure of connectedness into two subcategories: independent director connections and non-independent director connections. Panel E reports the regression estimates. We find that connections stemming from both independent and non-independent directors have strong influence on innovation (a test of equality of coefficients between these two measures cannot reject the null). Given that independent directors could arguably perform better monitoring, our finding also implies that the advising channel is at least as important as the monitoring channel.

Our last test pertains to how the relative prestige of directorship can vary the effect of board connectedness on innovation. Masulis and Mobbs (2014) show that due to reputation incentives, independent directors devote their priority unequally among firms when they have multiple directorships. They further note that directors consider larger firms with greater prestige as larger firms sustain directors relatively more visibility, higher compensation, and greater probability of receiving future directorships. Hence, similar to Masulis and Mobbs (2014), for each independent director, we first identify the relative importance of all her directorships based on firm size. Specifically, the directorship of an independent director in the focal firm is defined as high ranked if the firm is at least 10% larger in market capitalization than the smallest firm where she holds directorship, whereas her directorships in other firms are treated as low ranked. We then aggregate the connections stemming from directors with high (low) ranked directorship for each firm.[[34]](#footnote-34) Panel F reports the results. The coefficient on high ranked connections is positive and significant at the 1% level in all three models while the coefficient on low ranked connections is marginally significant at 10% level for two out of three models. This finding supports that reputation incentives differentiate directors’ involvement on a firm’s board.[[35]](#footnote-35)

**B. Innovation input, originality, and generality**

To better understand the effect of board connectedness, we test whether it is associated with the change in innovation input and the fundamental nature of innovative projects. We use R&D expenditure scaled by total assets as the dependent variable to proxy for corporate innovation input and re-estimate our baseline regression. Model 1 of Table 10 reports the regression estimates and shows that well-connected boards lead firms to invest more in R&D. Following Hall, Jaffe, and Trajtenberg (2005), we construct two variables, *originality* and *generality*, that use the distribution of citations to evaluate the fundamental value of patents. Originality is defined as one minus the Herfindahl index of the technology class distribution of cited patents while generality is defined as one minus the Herfindahl index of the technology class distribution of citing patents. A patent that cites a diverse range of technology classes of patents is regarded as having greater originality while a patent that is cited by a diverse range of technology classes of patents is regarded as having greater generality. The results from Models 2 and 3 indicate that board networks facilitate greater information flow, the resulting improvement in board effectiveness help to nurture patents that are more novel and have greater influence in broader technology fields.[[36]](#footnote-36)

1. **Conclusion**

Networks have been recognized as an important conduit for information exchange. In this paper we provide evidence that board connectedness has economically significant impacts on firm patenting activities that are crucial for firms’ competitive advantage. In particular, we find well-connected boards foster corporate innovation in terms of patent and subsequent citation counts. We address endogeneity issue by including a set of additional controls that might affect innovation, replacing lead and lag terms of dependent and independent variables, respectively, and utilizing the deaths and retirements of directors and the new listing requirements of SOX as exogenous shock to board connections. With the instrumental variable approach as another attempt, our study establishes a causal effect of board connectedness on innovation. In addition, our findings provide a deeper understanding regarding how the potential mechanisms affect the cross-sectional variations of the effect of board connectedness on corporate policies. Specifically, we find that the positive effect of board network on innovation is more pronounced when the firm has greater advising need or agency conflicts are severe.

We further provide evidence that the impact of board connectedness varies with types and relatedness of connections as well as director types and involvement. Overall, our results highlight the importance of board connectedness when evaluating the effect of board on corporate decision making and value implications.

Appendix: Definition of the variables used in the analyses

|  |  |
| --- | --- |
| # of segments | Indicator variable equal to 1 if the number of segments of a firm is greater than or equal to 3. |
| After | Indicator variable equal to 1 for years after the death or retirement of a director. |
| Board network | Natural logarithm of 1 plus the number of persons with whom directors share a common employment, education, or other social history. |
| Board size | Total number of board members in the firm. |
| CAPX | Ratio of capital expenditure to total assets. |
| Central (Non-central) network | Natural logarithm of 1 plus the number of connections from better-connected (less-connected) individuals. An individual is defined as better-connected (less-connected) if the number of her connections is above (below) the sample median.  |
| CEO connections | Natural logarithm of 1 plus the number of external individuals with whom a CEO shares a common employment, education, or other social history. |
| CEO duality | Indicator variable equal to 1 if the CEO is also the chairman of the board. |
| CEO-director ties | Natural logarithm of 1 plus the number of shared employment, education and other social connections between directors and CEO. |
| CHE | Ratio of cash to total assets. |
| Connected | Indicator variable equal to 1 if the departing director has at least one external connection. |
| Co-opted board | Ratio of the number of directors appointed by the incumbent CEO to board size. |
| Delta | Dollar change in CEO’s wealth for a 1% change in firm’s stock price following Core and Guay (2002). |
| Director age | Natural logarithm of 1 plus the average of directors’ age in the firm. |
| Director tenure | Natural logarithm of 1 plus average of directors’ tenure in the firm. |
| Education network | Natural logarithm of 1 plus the number of persons with whom directors share a common education background. |
| E-index | The Entrenchment index of Bebchuk, Cohen, and Ferrell (2009). |
| Employment network | Natural logarithm of 1 plus the number of persons with whom directors share a common employment history. |
| Generality | One minus the Herfindahl index of the technology class distribution of citing patents. |
| G-index | The Antitakeover index of Gompers, Ishii, and Metrick (2003). |
| Graduate degree | Natural logarithm of 1 plus the number of directors with a graduate degree. |
| Herfindahl index | Sales-based Herfindahl index based on 2-digit SIC code. |
| High (Low) ranked network | Natural logarithm of 1 plus the number of connections stemming from high (low) ranked directors. A director is defined as high ranked if the firm is at least 10% larger in market capitalization than the smallest firm where the director holds directorship. All other directors are treated as low ranked.  |
| Historical network | Natural logarithm of 1 plus the number of first-year connections from directors’ previous job. |
| Independent board | Fraction of independent directors in the board. |
| Independent (Non-independent) network | Natural logarithm of 1 plus the number of connections of independent (non-independent) directors. |
| Innovative ind. (Non-innovative) network | Natural logarithm of 1 plus the number of connections that are with individuals from innovative (non-innovative) industries. An industry is innovative if the average weighting-index adjusted citations per patent is above the sample median across industries. |
| Institutional holdings | Percentage of a firm's outstanding shares held by institutional investors. |
| Leverage | Ratio of the sum of short-term debt and long-term debt to total assets. |
| Ln(Patent) | Natural logarithm of 1 plus the number of patents filed in a given year that were eventually granted. |
| Ln(Qcitation) | Natural logarithm of 1 plus the number of subsequent citations received by patents filed and granted in a given year, adjusted by weighting-index. |
| Ln(TTcitation) | Natural logarithm of 1 plus the number of subsequent citations received by patents filed and granted in a given year, adjusted for technology class-year fixed effect. |
| Network dummy | Indicator variable equal to 1 if the number of a firm’s connections is above the sample median. |
| No. of departures | Total number of director departures due to deaths and retirements. |
| No. of industries | Average number of industries that directors have worked in. |
| Noncompliant | Indicator variable equal to 1 for firms not compliant to SOX requirement in 2001. |
| Originality | One minus the Herfindahl index of the technology class distribution of cited patents. |
| PP&E | Ratio of property, plant, and equipment to total assets. |
| R&D | Ratio of research and development expenditures to total assets. |
| Residual network | Natural logarithm of 1 plus the de-trend number of connections. |
| ROA | Ratio of operating income before depreciation to total assets. |
| Sales | Natural logarithm of total sales. |
| Same (Other) ind. network | Natural logarithm of 1 plus the number of connections that are with individuals from the same (a different) industry as the focal firm. |
| Size | Natural logarithm of 1 plus total assets. |
| Social network | Natural logarithm of 1 plus the number of persons with whom directors share a common active membership in a non-business organization. |
| SOX | Indicator variable equal to 1 for the period after 2001 (post-SOX period). |
| Tobin’s Q | Ratio of book value of assets minus the book value of equity plus the market value of equity to total assets. |

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Table 1: Summary statistics

This table reports the summary statistics for variables used in the empirical analysis. The sample consists of 54,398 firm-year observations between 1990 and 2008. Definitions of variables are provided in the Appendix.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | p25 | mean | Median | p75 | STD |
| Patent | 0.000 | 13.737 | 0.000 | 1.000 | 94.484 |
| Qcitation | 0.000 | 126.247 | 0.000 | 0.000 | 1,410.690 |
| TTcitation | 0.000 | 8.677 | 0.000 | 0.000 | 83.233 |
| Originality | 0.000 | 0.189 | 0.000 | 0.000 | 0.365 |
| Generality | 0.000 | 0.169 | 0.000 | 0.000 | 0.348 |
| Board network – Total | 140.000 | 654.670 | 408.000 | 900.000 | 741.054 |
| Board network – Employment | 43.000 | 346.607 | 183.000 | 483.000 | 443.510 |
| Board network – Education | 59.000 | 296.682 | 175.000 | 394.000 | 367.251 |
| Board network – Social activity | 0.000 | 11.331 | 0.000 | 2.000 | 51.972 |
| R&D | 0.000 | 0.062 | 0.004 | 0.072 | 0.125 |
| Leverage | 0.019 | 0.213 | 0.172 | 0.338 | 0.210 |
| CHE | 0.024 | 0.194 | 0.095 | 0.289 | 0.228 |
| CAPX | 0.020 | 0.060 | 0.040 | 0.076 | 0.064 |
| PP&E | 0.092 | 0.268 | 0.202 | 0.382 | 0.224 |
| Size | 58.337 | 2,202.039 | 219.555 | 905.186 | 13,540.128 |
| Tobin’s Q | 1.129 | 2.141 | 1.538 | 2.383 | 1.832 |
| ROA | 0.037 | 0.059 | 0.114 | 0.174 | 0.234 |
| Herfindahl index | 0.077 | 0.180 | 0.124 | 0.220 | 0.155 |
| Board size | 4.000 | 6.296 | 6.000 | 9.000 | 3.430 |
| Co-opted board | 1.000 | 3.194 | 3.000 | 5.000 | 2.646 |
| Independent board | 0.182 | 0.453 | 0.500 | 0.714 | 0.306 |

Table 2: Univariate comparison

This table reports the univariate comparison between well-connected firms and poorly-connected firms. A firm is defined as well-connected (poorly-connected) if the number of connections is above (below) the sample median. Definitions of variables are provided in the Appendix. T-test is conducted to test for differences in mean values of the two groups. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

|  |  |  |
| --- | --- | --- |
|  | Poorly-connected | Well-connected |
| Number of patents | 2.147 | 54.440\*\*\* |
| Number of Qcitations | 63.390 | 851.589\*\*\* |
| Number of TTcitations | 2.994 | 53.600\*\*\* |
| R&D | 0.056 | 0.068\*\*\* |
| Leverage | 0.209 | 0.218\*\*\* |
| CHE | 0.187 | 0.201\*\*\* |
| CAPX | 0.062 | 0.059\*\*\* |
| PP&E | 0.273 | 0.263\*\*\* |
| Size | 4.674 | 6.354\*\*\* |
| Tobin’s Q | 2.041 | 2.240\*\*\* |
| ROA | 0.046 | 0.073\*\*\* |
| Herfindahl index | 0.181 | 0.177\*\*\* |
| Board size | 1.629 | 2.081\*\*\* |

Table 3: Board connectedness and innovation

This table reports the regression results on the effect of board connectedness on firm innovation. Models 1 and 4 use patent counts as the dependent variable. Models 2, 3, 5, and 6 use citation counts adjusted by weighting index and technology class-year fixed effect, respectively. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 　 | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Board network | 0.060\*\*\* | 0.123\*\*\* | 0.060\*\*\* |  |  |  |
|  | (5.94) | (6.40) | (5.80) |  |  |  |
| Network dummy |  |  |  | 0.041\* | 0.135\*\*\* | 0.052\*\* |
|  |  |  |  | (1.85) | (3.46) | (2.32) |
| R&D | 1.330\*\*\* | 2.780\*\*\* | 1.317\*\*\* | 1.384\*\*\* | 2.869\*\*\* | 1.367\*\*\* |
|  | (12.17) | (13.34) | (11.49) | (12.60) | (13.74) | (11.90) |
| Leverage | -0.327\*\*\* | -0.606\*\*\* | -0.316\*\*\* | -0.329\*\*\* | -0.612\*\*\* | -0.319\*\*\* |
|  | (-5.74) | (-6.45) | (-5.55) | (-5.77) | (-6.50) | (-5.59) |
| CHE | 0.203\*\*\* | 0.684\*\*\* | 0.287\*\*\* | 0.224\*\*\* | 0.717\*\*\* | 0.306\*\*\* |
|  | (3.38) | (6.47) | (4.53) | (3.74) | (6.79) | (4.84) |
| CAPX | 0.698\*\*\* | 1.512\*\*\* | 0.842\*\*\* | 0.719\*\*\* | 1.546\*\*\* | 0.861\*\*\* |
|  | (4.87) | (5.76) | (5.85) | (5.00) | (5.87) | (5.96) |
| PP&E | -0.097 | -0.056 | -0.104 | -0.107 | -0.072 | -0.113 |
|  | (-1.15) | (-0.41) | (-1.28) | (-1.27) | (-0.52) | (-1.39) |
| Size | 0.352\*\*\* | 0.542\*\*\* | 0.330\*\*\* | 0.364\*\*\* | 0.562\*\*\* | 0.341\*\*\* |
|  | (24.82) | (29.11) | (25.58) | (24.86) | (29.95) | (25.81) |
| Tobin’s Q | 0.055\*\*\* | 0.115\*\*\* | 0.063\*\*\* | 0.056\*\*\* | 0.116\*\*\* | 0.064\*\*\* |
|  | (9.93) | (11.41) | (10.58) | (10.01) | (11.48) | (10.64) |
| ROA | 0.116\*\* | 0.408\*\*\* | 0.155\*\*\* | 0.107\*\* | 0.392\*\*\* | 0.146\*\*\* |
|  | (2.16) | (4.08) | (2.80) | (1.99) | (3.91) | (2.64) |
| Herfindahl index | 0.179\* | 0.347\*\* | 0.151 | 0.177\* | 0.344\*\* | 0.149 |
|  | (1.92) | (2.35) | (1.64) | (1.89) | (2.31) | (1.61) |
| Board size | 0.069\*\* | 0.126\*\* | 0.063\*\* | 0.132\*\*\* | 0.233\*\*\* | 0.121\*\*\* |
|  | (2.46) | (2.39) | (2.21) | (4.79) | (4.69) | (4.41) |
|  |  |  |  |  |  |  |
| Obs. | 54,398 | 54,398 | 54,398 | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.421 | 0.407 | 0.383 | 0.419 | 0.406 | 0.381 |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes | Yes | Yes | Yes |

Table 4: Board connectedness and innovation: Robustness checks

This table reports the regression results of robustness tests on the effect of board connectedness on firm innovation. Panel A provides results based on alternative measures of board connectedness, negative binomial model specification, firms with at least one patent in a given year, and additional control variables. Panel B provides results using three-year lead patent related information as dependent variables, including one-year lagged value of innovation measures as control variables, and results using historical connections as an alternative measure of board connectedness. Panel C provides results with additional variables as controls to address issue of correlated omitted variable. In each panel, Model 1 presents the results using patent counts as the dependent variable while Models 2 and 3 present the results using citations counts adjusted by weighting index and technology class-year fixed effect, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

Panel A: Robustness checks

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| A1: Residual connections |
| Residual network | 0.355\*\*\* | 0.316\* | 0.229\*\* |
|  | (3.13) | (1.71) | (1.99) |
| A2: Ratio of connections to board size |
| Board network/board size | 0.002\*\*\* | 0.002\*\*\* | 0.002\*\*\* |
|  | (9.35) | (8.39) | (9.21) |
| A3: Negative binomial model  |
| Board network | 0.180\*\*\* | 0.156\*\*\* | 0.129\*\* |
|  | (4.82) | (3.23) | (2.57) |
| A4: Excluding firm-year with no patent information |
| Board network | 0.066\*\*\* | 0.111\*\*\* | 0.081\*\*\* |
|  | (3.41) | (3.70) | (3.64) |
| A5: Co-opted board |
| Board network | 0.074\*\*\* | 0.159\*\*\* | 0.071\*\*\* |
|  | (5.16) | (6.11) | (4.89) |
| Co-opted board | -0.051 | -0.005 | -0.033 |
|  | (-1.31) | (-0.08) | (-0.83) |
| A6: CEO-director ties |
| Board network | 0.084\*\*\* | 0.168\*\*\* | 0.080\*\*\* |
|  | (5.42) | (5.85) | (4.98) |
| CEO-director ties | -0.054\*\* | -0.107\*\*\* | -0.050\* |
|  | (-2.07) | (-2.60) | (-1.94) |
| A7: Fraction of independent board |
| Board network | 0.060\*\*\* | 0.123\*\*\* | 0.060\*\*\* |
|  | (5.97) | (6.41) | (5.83) |
| Independent board | 0.180\*\*\* | 0.269\*\*\* | 0.182\*\*\* |
|  | (3.82) | (3.07) | (3.74) |
| A8: CEO connections |
| Board network | 0.042\*\* | 0.109\*\*\* | 0.044\*\*\* |
|  | (2.52) | (3.52) | (2.59) |
| CEO connections | 0.057\*\*\* | 0.080\*\*\* | 0.047\*\*\* |
|  | (5.45) | (4.35) | (4.40) |
| A9: Institutional holdings |
| Board network | 0.069\*\*\* | 0.131\*\*\* | 0.067\*\*\* |
|  | (6.73) | (6.73) | (6.44) |
| Institutional holdings | -0.522\*\*\* | -0.487\*\*\* | -0.449\*\*\* |
|  | (-7.14) | (-4.77) | (-6.69) |
| A10: G-index |
| Board network | 0.153\*\*\* | 0.268\*\*\* | 0.147\*\*\* |
|  | (5.36) | (5.72) | (5.15) |
| G-index | 0.001 | 0.017 | 0.001 |
|  | (0.13) | (1.11) | (0.13) |

Panel B: Reverse causality

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| B1: 3-year lead innovation measures |
| Board network | 0.061\*\*\* | 0.115\*\*\* | 0.058\*\*\* |
|  | (5.24) | (5.43) | (4.91) |
| B2: including 1-year lagged innovation measures |
| Board network | 0.006\*\*\* | 0.029\*\*\* | 0.010\*\*\* |
|  | (3.03) | (4.98) | (4.26) |
| B3: Historical connections |
| Historical network | 0.052\*\*\* | 0.112\*\*\* | 0.052\*\*\* |
|  | (5.10) | (5.77) | (4.99) |

Panel C: Omitted variables

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| C1: Director age |
| Board network | 0.061\*\*\* | 0.125\*\*\* | 0.060\*\*\* |
|  | (5.93) | (6.45) | (5.75) |
| Director age | -0.004 | 0.044 | -0.044 |
|  | (-0.05) | (0.27) | (-0.49) |
| C2: Graduate degree |
| Board network | 0.036\*\*\* | 0.099\*\*\* | 0.038\*\*\* |
|  | (3.35) | (4.86) | (3.53) |
| Graduate degree | 0.134\*\*\* | 0.142\*\*\* | 0.118\*\*\* |
|  | (5.66) | (3.29) | (4.81) |
| C3: Director tenure |
| Board network | 0.061\*\*\* | 0.128\*\*\* | 0.061\*\*\* |
|  | (5.90) | (6.49) | (5.72) |
| Director tenure | 0.005 | 0.022 | 0.002 |
|  | (0.29) | (0.74) | (0.10) |
| C4: Firm fixed effects |
| Board network | 0.023\*\* | 0.074\*\*\* | 0.027\*\*\* |
|  | (2.38) | (3.67) | (2.71) |

Table 5: Board connectedness and innovation: Retirement and death of directors

This table reports the regression results based on the events of deaths and retirements of directors. The event window is a 5-year window period centered on the event. Panel A reports the results using the sample based on the events of both deaths and retirements. Panels B (C) reports the results using events based on the sample of deaths (sudden deaths) of directors only. Panel D reports the results using pseudo-events based on the sample of deaths and retirements of directors. A pseudo-event year is constructed by shifting a given actual event year three years earlier. Panel E (F) reports the results using pseudo-events based on the sample of deaths (sudden deaths) of directors only. In each panel, Model 1 presents the results using patent counts as the dependent variable while Models 2 and 3 present the results using citation counts adjusted by weighting index and technology class-year fixed effect, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include firm and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

Panel A: Full sample

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | -0.153\*\*\* | -0.232\*\*\* | -0.149\*\*\* |
|  | (-5.62) | (-4.73) | (-4.93) |
| After | -0.099\*\*\* | -0.297\*\*\* | -0.121\*\*\* |
|  | (-4.30) | (-6.89) | (-4.60) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 17,582 | 17,582 | 17,582 |
| Adj. R2 | 0.865 | 0.813 | 0.824 |
| Firm FE | Yes | Yes | Yes |

Panel B: Death only sample

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | -0.204\*\*\* | -0.319\*\*\* | -0.196\*\*\* |
|  | (-3.14) | (-2.69) | (-2.79) |
| After | -0.074 | -0.263\*\*\* | -0.106\* |
|  | (-1.59) | (-2.62) | (-1.95) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 2,170 | 2,170 | 2,170 |
| Adj. R2 | 0.867 | 0.818 | 0.832 |
| Firm FE | Yes | Yes | Yes |

Panel C: Sudden death sample

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | -0.343\* | -0.599\* | -0.476\*\* |
|  | (-1.68) | (-1.89) | (-2.02) |
| After | -0.112 | -0.262 | 0.273 |
|  | (-0.89) | (-1.25) | (1.29) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 371 | 371 | 371 |
| Adj. R2 | 0.897 | 0.870 | 0.875 |
| Firm FE | Yes | Yes | Yes |

Panel D: Full sample – pseudo events

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | 0.006 | -0.058 | 0.005 |
|  | (0.34) | (-1.44) | (0.23) |
| After | -0.065\*\*\* | -0.204\*\*\* | -0.078\*\*\* |
|  | (-3.61) | (-5.18) | (-3.89) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 25,540 | 25,540 | 25,540 |
| Adj. R2 | 0.916 | 0.856 | 0.885 |
| Firm FE | Yes | Yes | Yes |

Panel E: Death only sample - pseudo events

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | -0.041 | -0.145 | -0.045 |
|  | (-0.88) | (-1.60) | (-0.77) |
| After | 0.018 | -0.054 | -0.004 |
|  | (0.49) | (-0.65) | (-0.08) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 2,626 | 2,626 | 2,626 |
| Adj. R2 | 0.908 | 0.758 | 0.867 |
| Firm FE | Yes | Yes | Yes |

Panel F: Sudden death sample - pseudo events

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| After \* Connected | 0.019 | 0.010 | 0.104 |
|  | (0.16) | (0.04) | (0.75) |
| After | 0.126 | 0.294 | 0.118 |
|  | (1.27) | (1.19) | (0.89) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 462 | 462 | 462 |
| Adj. R2 | 0.930 | 0.883 | 0.887 |
| Firm FE | Yes | Yes | Yes |

Table 6: Board connectedness and innovation: the clean estimate from SOX

This table reports the regression results by exploiting the Sarbanes-Oxley Act (SOX) that requires a majority of directors to be independent. Non-compliant firms must add independent directors to fulfill the new listing requirement which generates exogenous variations in board connectedness. The sample for this test contains four years around the event year of 2002. Model 1 presents the results using patent counts as the dependent variable while Models 2 and 3 present the results using citation counts adjusted by weighting index and technology class-year fixed effect, respectively. The “clean” effect of board connectedness is reported at the bottom of the table. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Board network | 0.316\*\*\* | 0.549\*\*\* | 0.309\*\*\* |
|  | (10.91) | (11.30) | (10.55) |
| Board network\*SOX | -0.115\*\*\* | -0.277\*\*\* | -0.108\*\*\* |
|  | (-5.39) | (-8.04) | (-5.22) |
| Noncompliant\*Board network | -0.249\*\*\* | -0.362\*\*\* | -0.246\*\*\* |
|  | (-8.13) | (-7.31) | (-8.28) |
| SOX\*Noncompliant\*Board network | 0.091\*\* | 0.161\*\*\* | 0.094\*\* |
|  | (2.16) | (2.73) | (2.35) |
| SOX\*Noncompliant | -0.449\* | -0.713\* | -0.426\* |
|  | (-1.65) | (-1.89) | (-1.67) |
| SOX | 0.611\*\*\* | 1.506\*\*\* | 0.590\*\*\* |
|  | (4.32) | (6.67) | (4.33) |
| Noncompliant | 1.449\*\*\* | 2.067\*\*\* | 1.425\*\*\* |
|  | (8.50) | (7.29) | (8.52) |
|  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 25,335 | 25,335 | 25,335 |
| Adj. R2 | 0.446 | 0.425 | 0.406 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |
| Clean estimate () | 0.158\*\*\*(8.81) | 0.348\*\*\*(22.71) | 0.157\*\*\*(9.72) |

Table 7: Board connectedness and innovation: Instrumental variable approach

This table reports the regression results based on the instrumental variable approach. Model 1 reports the first stage regression estimates, with two instrument variables, the average number of industries that directors have worked in and the total number of director departures due to deaths and retirements. Model 2 presents the results using patent counts as the dependent variable while Models 3 and 4 present the results using citation counts adjusted by weighting index and technology class-year fixed effect, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | (1) |  | (2) | (3) | (4) |
|  | First stage |  | Second stage |
|  | Board network |  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Board network |  |  | 0.132\*\*\* | 0.419\*\*\* | 0.246\*\*\* |
|  |  |  | (4.79) | (5.45) | (5.84) |
| No. of industries | 0.284\*\*\* |  |  |  |  |
|  | (28.54) |  |  |  |  |
| No. of departures | -0.026\*\*\* |  |  |  |  |
|  | (-2.96) |  |  |  |  |
|  |  |  |  |  |  |
|  | All other control variables from Table 3 |
| Obs. | 31,083 |  | 31,083 | 31,083 | 31,083 |
| Adj. R2 | 0.627 |  | 0.270 | 0.267 | 0.248 |
| Year FE | Yes |  | Yes | Yes | Yes |
| Industry FE | Yes |  | Yes | Yes | Yes |
| F stat | 414.39 |  |  |  |  |
| p-value (Hansen J) |  |  | 0.18 | 0.34 | 0.19 |

Table 8: Potential mechanisms: Board advising vs. monitoring

This table reports the regression results using samples split based on the degree of demand of board advising and monitoring, respectively. Panel A reports the results using firm size (sales), number of segments, and R&D expenditures as measures for the degree of the advising needs. Panel B reports the results using E-index, CEO duality, and Delta as measures for the degree of agency problem, i.e. monitoring needs. Firms are assigned into *High* (*Low*) group if the degree of a given proxy is above (below) the sample median. The Wald tests compare the coefficients on board network between *High* and *Low* groups. Models 1 and 2 present the results using patent counts as the dependent variable while Models 3 – 6 present the results using citation counts adjusted by weighting index and technology class-year fixed effect, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

Panel A: Advising

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Panel A1: Sales |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |  |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.028\*\*\* | 0.087\*\*\* | 0.074\*\*\* | 0.155\*\*\* | 0.032\*\*\* | 0.079\*\*\* |
|  | (3.98) | (4.69) | (3.93) | (4.93) | (4.03) | (4.27) |
|  | All models include control variables from Table 3  |
| Wald test | 52.87\*\*\* | 24.18\*\*\* | 30.82\*\*\* |
| Obs. | 27,191 | 27,203 | 27,191 | 27,203 | 27,191 | 27,203 |
| Adj. R2 | 0.281 | 0.545 | 0.260 | 0.547 | 0.221 | 0.519 |
| Panel A2: # of segments |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |  |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.050\*\*\* | 0.098\*\*\* | 0.111\*\*\* | 0.163\*\*\* | 0.053\*\*\* | 0.083\*\*\* |
|  | (5.26) | (3.97) | (5.67) | (3.95) | (5.43) | (3.38) |
|  | All models include control variables from Table 3  |
| Wald test | 17.39\*\*\* | 5.60\*\* | 6.10\*\* |
| Obs. | 36,732 | 17,666 | 36,732 | 17,666 | 36,732 | 17,666 |
| Adj. R2 | 0.388 | 0.479 | 0.378 | 0.470 | 0.346 | 0.446 |
| Panel A3: R&D |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |  |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.027\*\*\* | 0.041\*\* | 0.060\*\*\* | 0.091\*\*\* | 0.025\*\*\* | 0.046\*\*\* |
|  | (4.25) | (2.55) | (4.41) | (2.95) | (4.09) | (2.67) |
|  | All models include control variables from Table 3  |
| Wald test | 4.04\*\* | 3.97\* | 7.32\*\*\* |
| Obs. | 27,208 | 27,190 | 27,208 | 27,190 | 27,208 | 27,190 |
| Adj. R2 | 0.189 | 0.530 | 0.160 | 0.465 | 0.158 | 0.471 |

Panel B: Monitoring

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Panel B1: E-index |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.100\*\* | 0.236\*\*\* | 0.211\*\*\* | 0.374\*\*\* | 0.107\*\*\* | 0.214\*\*\* |
|  | (2.54) | (6.09) | (3.35) | (5.54) | (2.72) | (5.40) |
|  | All models include control variables from Table 3 |
| Wald test | 34.28\*\*\* | 15.44\*\*\* | 19.91\*\*\* |
| Obs. | 9,561 | 8,331 | 9,561 | 8,331 | 9,561 | 8,331 |
| Adj. R2 | 0.584 | 0.559 | 0.580 | 0.550 | 0.562 | 0.527 |
| Panel B2: CEO duality |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.049\*\*\* | 0.071\*\*\* | 0.109\*\*\* | 0.144\*\*\* | 0.051\*\*\* | 0.069\*\*\* |
|  | (5.11) | (4.07) | (5.18) | (4.61) | (4.97) | (3.95) |
|  | All models include control variables from Table 3  |
| Wald test | 8.11\*\*\* | 4.62\*\* | 5.33\*\* |
| Obs. | 27,715 | 26,683 | 27,715 | 26,683 | 27,715 | 26,683 |
| Adj. R2 | 0.360 | 0.469 | 0.343 | 0.465 | 0.315 | 0.436 |
| Panel B3: Delta |  |  |  |  |  |
|  | Ln(Patent) | Ln(Qcitation) |  Ln(TTcitation) |
|  | (1) | (2) | (3) | (4) | (5) | (6) |
|  | Low | High | Low | High | Low | High |  |
| Board network | 0.116\*\*\* | 0.184\*\*\* | 0.237\*\*\* | 0.338\*\*\* | 0.121\*\*\* | 0.172\*\*\* |
|  | (3.84) | (4.55) | (4.35) | (4.86) | (4.00) | (4.14) |
|  | All models include control variables from Table 3  |
| Wald test | 8.34\*\*\* | 5.36\*\* | 4.27\*\* |
| Obs. | 9,156 | 9,163 | 9,156 | 9,163 | 9,156 | 9,163 |
| Adj. R2 | 0.454 | 0.599 | 0.453 | 0.597 | 0.413 | 0.573 |

Table 9: Heterogeneity in network

This table reports the regression results based on network types and director characteristics. Panel A reports the results based on different types of board connections in terms of how the connection is created. Panel B reports the results based on whether connections are with firms in the same industry or not. Panel C reports the results based on whether the connections are with firms in highly innovative industries or not. Panel D reports the results based on whether the connections are with well-connected individuals or not. Panel E reports the results of tests partitioning connections into independent directors’ and non-independent directors’ connections. Panel F reports the results of tests splitting connections into high ranked directors’ and low ranked directors’ connections. An independent director is defined as high ranked if the firm is at least 10% larger in market capitalization than the smallest firm where the director holds directorship. All other independent directors are defined as low ranked. Model 1 presents the results using patent counts as the dependent variable while Models 2 and 3 present the results using citation counts adjusted by weighting index and technology class-year fixed effect, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

Panel A: Different types of board connections

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Employment network | 0.067\*\*\* | 0.151\*\*\* | 0.071\*\*\* |
|  | (6.59) | (7.85) | (6.89) |
| Education network | 0.014\* | 0.027\*\* | 0.014\* |
|  | (1.88) | (1.96) | (1.87) |
| Social network | 0.063\*\*\* | 0.052\*\*\* | 0.048\*\*\* |
|  | (4.66) | (2.64) | (3.64) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.426 | 0.410 | 0.386 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Panel B: Same industry

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Same ind. network | 0.067\*\*\* | 0.136\*\*\* | 0.073\*\*\* |
|  | (5.72) | (6.41) | (6.07) |
| Other ind. network | 0.021\*\* | 0.041\*\* | 0.018 |
|  | (1.98) | (2.03) | (1.60) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.422 | 0.409 | 0.384 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Panel C: Innovative industry

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Innovative ind. network | 0.001\*\*\* | 0.001\*\*\* | 0.001\*\*\* |
|  | (4.84) | (3.90) | (4.13) |
| Non-innovative ind. network | 0.0002\*\* | 0.0002 | 0.0002\*\* |
|  | (2.21) | (1.51) | (2.07) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.445 | 0.416 | 0.403 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Panel D: Centrality

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Central network | 0.034\*\*\* | 0.086\*\*\* | 0.035\*\*\* |
|  | (3.56) | (4.69) | (3.55) |
| Non-central network | 0.022 | 0.020 | 0.020 |
|  | (1.28) | (0.62) | (1.14) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.420 | 0.407 | 0.382 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Panel E: Independent directorship

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| Independent network | 0.042\*\*\* | 0.076\*\*\* | 0.042\*\*\* |
|  | (5.87) | (5.84) | (5.89) |
| Non-independent network | 0.038\*\*\* | 0.075\*\*\* | 0.036\*\*\* |
|  | (6.17) | (6.58) | (5.84) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.422 | 0.409 | 0.384 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Panel F: Rank

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | Ln(Patent) | Ln(Qcitation) | Ln(TTcitation) |
| High ranked network | 0.038\*\*\* | 0.065\*\*\* | 0.037\*\*\* |
|  | (4.42) | (4.07) | (4.16) |
| Low ranked network | 0.007 | 0.016\* | 0.010\* |
|  | (1.32) | (1.84) | (1.72) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 40,864 | 40,864 | 40,864 |
| Adj. R2 | 0.437 | 0.425 | 0.398 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

Table 10: Innovation input, originality, and generality

This table reports the regression results on the effect of board connectedness on firm innovation input, originality and generality. Model 1 uses R&D scaled by total assets as the dependent variable. Models 2 and 3 use patent originality and generality as dependent variables, respectively. All other controls as in Table 3 are included but not reported for brevity. Definitions of variables are provided in the Appendix. All specifications include industry and year fixed effects. T-statistics reported in parenthesis are robust and clustered by firm. \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10% level, respectively.

|  |  |  |  |
| --- | --- | --- | --- |
|  | (1) | (2) | (3) |
|  | R&D | Originality | Generality |
| Board network | 0.008\*\*\* | 0.014\*\*\* | 0.013\*\*\* |
|  | (11.57) | (4.72) | (4.69) |
|  |  |  |  |
|  | All models include control variables from Table 3 |
| Obs. | 54,398 | 54,398 | 54,398 |
| Adj. R2 | 0.626 | 0.323 | 0.312 |
| Year FE | Yes | Yes | Yes |
| Industry FE | Yes | Yes | Yes |

1. \* We thank Mark Walker, Sean Flynn, and Yuri Tserlukevich for helpful comments. We also thank seminar participants at National Taiwan University. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)
3. \*\* Chang is with College of Management, National Taiwan University, No.1,Sec. 4, Roosevelt Rd., Taipei City 106, Taiwan. chinghungc@ntu.edu.tw. Wu is with Poole College of Management, North Carolina State University, 2801 Founders Drive, Raleigh, NC 27695. qingqing\_wu@ncsu.edu. [↑](#footnote-ref-3)
4. For example, Romer (1990) and Porter (1992). [↑](#footnote-ref-4)
5. See also, among others, Holmström (1982, 1989), Narayanan (1985), and Shleifer and Vishny (1990). [↑](#footnote-ref-5)
6. American Bar Association's Committee on Corporate Laws (1994) [↑](#footnote-ref-6)
7. Faleye, Hoitash, and Hoitash (2013) study the characteristics of advisory directors and their impact on firm policies based on committee assignments. [↑](#footnote-ref-7)
8. In another news article, when Barry Fishman was appointed as an independent director of Aurora, he also mentioned that he will devote his effort to corporate governance and strategical decision making. “Accomplished Pharma CEO and Cannabis Sector Director Further Strengthens Corporate Governance”, CNW, October 12, 2016. [↑](#footnote-ref-8)
9. Prior studies provide evidence that network in a variety of forms tends to have value impacts through information dissemination. See, for example, Cohen, Frazzini, and Malloy (2008, 2010), Coles, Wang, and Zhu (2015), Fracassi (2016), Engelberg, Gao, and Parsons (2012, 2013), Hochberg, Ljungqvist, and Lu (2007), among others. [↑](#footnote-ref-9)
10. See, for example, Pindyck (1993), Bernanke (1983), Dixit and Pindyck (1994), and Bloom, Bond, and Van Reenen (2007) [↑](#footnote-ref-10)
11. See also Majd and Pindyck (1987) and Pacheco-de-Almeida and Zemsky (2003), among others. [↑](#footnote-ref-11)
12. Using firm’s patenting activates as the measure of innovation output, although not perfect, has become a common practice in recent innovation literature. [↑](#footnote-ref-12)
13. For works showing the relation between innovation and long-term value, see Hall, Jaffe, and Trajtenberg (2005); Nicholas (2008); Pástor and Veronesi (2009) among others. [↑](#footnote-ref-13)
14. For more empirical works, see Aghion, Van Reenen, and Zingales (2013), Acharya, Baghai, and Subramanian (2013, 2014), Acharya and Subramanian (2009), Atanassov (2013), Bradley, Kim, and Tian (2016), He and Tian (2014) among others. [↑](#footnote-ref-14)
15. The board structure and directorship information reported in BoardEx starts in 1999 and the coverage becomes reliable in 2000. In untabulated tests, we limit our sample period starting from year 2000 and continue to find similar robust results. See also Kang, Liu, Low, and Zhang (2014) and Schmidt (2015) for a similar reconstruction of director information. [↑](#footnote-ref-15)
16. In untabulated results, we obtain similar robust results using only NBER patent database that restricts our sample period from 2000 to 2006. [↑](#footnote-ref-16)
17. Hall, Jaffe, and Trajtenberg (2001, 2005) show that the average of application–grant lag is around 2 years. [↑](#footnote-ref-17)
18. Results based on Wilcoxon-Mann-Whitney test provide a similar inference. [↑](#footnote-ref-18)
19. (900-140)/140\*0.06 = 33% [↑](#footnote-ref-19)
20. As we use the logarithm form of connections, we add the absolute value of smallest residual from the sample before taking the log-transformation. [↑](#footnote-ref-20)
21. For adjusted citations, we round the number of *Qcitations* and *TTcitations* to their nearest integer when performing the tests. [↑](#footnote-ref-21)
22. The reason that our results on CEO-director connections is different from that of Kang, Liu, Low, and Zhang (2014) could be mainly resulting from the inclusion of employment connections in our construction of variable while Kang et al. (2014) they only consider education and non-professional connections. [↑](#footnote-ref-22)
23. We obtain similar results when we use the number of directors with a MBA degree as an alternative proxy for director ability. [↑](#footnote-ref-23)
24. BoardEx provides information on retirements and deaths of directors from 1999. Hence, our sample period for the DID analysis is from 1999 to 2008. [↑](#footnote-ref-24)
25. For robustness, we set age of 70 as the cutoff. Although this further reduces the sample size, our results remain robust to this alternative setting. [↑](#footnote-ref-25)
26. We cannot include *Connected* in the regression as its effect is subsumed by firm fixed effects. [↑](#footnote-ref-26)
27. We obtain similar results if standard errors are clustered at the director level. [↑](#footnote-ref-27)
28. We search for keywords such as sudden, unexpected, and unanticipated. [↑](#footnote-ref-28)
29. See, for example, Johnson, Magee, Nagarajan, and Newman (1985), Hayes and Schaefer (1999), Falato, Kadyrzhanova, and Lel (2014), and Nguyen and Nielsen (2010). [↑](#footnote-ref-29)
30. In untabulated results, we regress board connections on a set of standard firm characteristics following the literature, including a dummy variable equal to 1 for years after 2001, a lagged term of board connections, and industry and year fixed effects. We find that non-compliant firms exhibit an increase in connections while compliant firms have no variations in connections. [↑](#footnote-ref-30)
31. In untabulated results, we use a 5-year window around year 2002 or full sample period and continue to obtain similar results. [↑](#footnote-ref-31)
32. See, for example, Coles, Daniel, and Naveen (2008) and Klein (1998). [↑](#footnote-ref-32)
33. Results are similar if we use Fama-French 48 industry classifications. [↑](#footnote-ref-33)
34. Our sample is smaller under this setting as our focus is on independent directors following Masulis and Mobbs (2014). [↑](#footnote-ref-34)
35. In untabulated results, we use sales as alternative proxy for firm size and the average of high (low) ranked connections. The results are robust to these adjustments. Also, we treat missing values of high (low) ranked connections as zero connections. The results are qualitatively invariant to this setting. [↑](#footnote-ref-35)
36. The results are similar when we use Tobit model to estimate the effect of board network since the originality and generality scores are bounded between 0 and 1. [↑](#footnote-ref-36)